REPORT TO CONGRESS

NASA Response to Recommendations in the National Research Council Decadal Survey of Civil Aeronautics

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EXECUTIVE SUMMARY

In August 2006, the National Research Council (NRC) released a report entitled "Decadal Survey of Civil Aeronautics: Foundation for the Future." The purpose of the study was to develop a decadal strategy for federal aeronautics research, with a particular emphasis on NASA's aeronautics research portfolio.

Guidelines for investment were developed for the following five Research and Technology (R&T) areas: (1) aerodynamics and aeroacoustics; (2) propulsion and power; (3) materials and structures; (4) dynamics, navigation, control, and avionics; and (5) intelligent and autonomous systems, operations and decision making, human integrated systems, and, networking and communications.

This report to Congress is in response to House Report 109-520, accompanying H.R. 5672, the FY 2007 Science, State, Justice, Commerce, and Related Agencies appropriations bill. House Report 109-520 requested that NASA respond to the recommendations of the Decadal Survey of Civil Aeronautics, including whether the Agency intends to implement all of the Survey's recommendations, and if not, providing a rationale for choosing not to implement a given recommendation.

The Decadal Survey provided a total of eight top-level recommendations, five of which were addressed specifically to NASA. (The remaining three were addressed to the broader U.S. Government.) This report will show that NASA is well-aligned with, and is implementing, the five NASA-specific recommendations. More specifically:

- 47 of the Survey's 51 R&T Challenges (92 percent) are well represented within NASA's aeronautics research portfolio.
- All 5 of the Survey's Common Themes are present throughout NASA's aeronautics research portfolio.
- NASA is conducting fundamental research that will help to provide the foundation for certification of new technologies.
- NASA is fostering intellectual partnerships with industry and academia by means of cooperative Space Act Agreements and fully and openly competed research awards that emphasize true collaborations among all partners
- NASA has established strong partnerships with other Government agencies and organizations, including the Federal Aviation Administration (FAA), Department of Defense (DOD), and the Joint Planning and Development Office (JPDO). As a member of the National Science and Technology Council (NSTC) Aeronautics Science and Technology Subcommittee, NASA is pursuing a coordinated approach with its Government partners to managing and utilizing the Nation's research, development, test, and evaluation (RDT&E) infrastructure, which includes test facilities as well as computational infrastructure.

It should also be pointed out that the Decadal Survey panelists noted that the existence of an explicit National Aeronautics Research and Development (R&D) Policy would have greatly facilitated their report. While a policy did not exist then, such a policy does exist today. On December 20, 2006, President George W. Bush issued Executive Order 13419, entitled "National Aeronautics Research and Development." Section 1 of the Order established a National Aeronautics Research and Development Policy. NASA's new aeronautics research portfolio closely aligns with the principles, goal, and objectives of the Policy, as has been documented in its Report to Congress, "NASA Response to the National Aeronautics R&D Policy", submitted February 2007. A copy of the document can be found on the NASA Aeronautics Research Mission Directorate (ARMD) website at www.aeronautics.nasa.gov.

I. OVERVIEW

In the fall of 2005, ARMD initiated a restructuring of its aeronautics portfolio to ensure that it had a strategic plan in place that enables the pursuit of long-term, cutting-edge research for the benefit of the broad aeronautics community. The restructuring was guided by three core principles: 1) NASA will dedicate itself to the mastery and intellectual stewardship of the core competencies of aeronautics in all flight regimes; 2) NASA will focus its research in areas appropriate to its unique capabilities; and 3) NASA will directly address the fundamental research needs of the Next Generation Air Transportation System (NGATS, or "NextGen") while working closely with its agency partners in the JPDO.

Using the above principles, ARMD established four programs: the Fundamental Aeronautics Program, the Aviation Safety Program, the Airspace Systems Program, and the Aeronautics Test Program. The Fundamental Aeronautics Program conducts cutting-edge research that produces innovative concepts, tools, and technologies that enable the design of vehicles that fly through any atmosphere at any speed. The Aviation Safety Program focuses on developing the cutting-edge tools, methods, and technologies to improve the intrinsic safety attributes of current and future aircraft that will operate in the NextGen system. The Airspace Systems Program directly addresses the Air Traffic Management (ATM) research needs of the NextGen initiative as defined by the JPDO. The Aeronautics Test Program ensures the strategic availability and accessibility of a critical suite of aeronautics test facilities that are deemed necessary to meet aeronautics, agency, and national needs. Additional information on the content of each program is provided for reference in Appendix A, and much more information, including detailed research plans with milestones and metrics, can be found at the ARMD website at www.aeronautics.nasa.gov.

The restructuring of NASA's aeronautics research program took into consideration many reports and studies that have been conducted over the past several years, including the "Final Report of the Commission on the Future of the U.S. Aerospace Industry" by the Aerospace Commission, 2002, "Securing the Future of U.S. Air Transportation: A System in Peril" by the NRC, (2003), "Wind Tunnel and Propulsion Test Facilities: An Assessment of NASA's Capabilities to Serve National Needs," RAND Corporation, (2003), and "Responding to the Call: Aviation Plan for American Leadership" by the National Institute of Aerospace, (2005).

While the "Decadal Survey of Civil Aeronautics" (2006) was published after the restructuring of NASA's aeronautics program was well underway, NASA's new aeronautics program is well-aligned with the NASA-specific recommendations presented in the Survey. Each section below cites one of the five NASA-specific recommendations from the Survey, and then provides a detailed explanation of how NASA is addressing that recommendation.

II. RECOMMENDATION #1

NASA should use the 51 Challenges listed in Table 5-1 as the foundation for the future of NASA's civil aeronautics research program during the next decade. [Table 5-1 refers to a table in the Survey.]

The ARMD research portfolio is well aligned with the recommended R&T Challenges. As indicated in the cross-walk matrix provided in Appendix B, 47 of the 51 R&T Challenges (92 percent) are currently being addressed in ARMD programs. The four Challenges that ARMD is not addressing are highlighted in red in the matrix, and an explanation regarding those four challenges is provided below.

The 4 Challenges NASA is not addressing:

- Challenge A7a addresses aerodynamic configurations to leverage advantages of formation flying. Research in this area has been conducted for many years by the Department of Defense (DOD), including DARPA and the Air Force, and it is appropriate for the DOD to take the lead in this research area.

- Challenge B9 focuses on research that enables high-reliability, high-performance, and high-power density aircraft electric power systems and is being addressed by the Department of Energy (DOE), DOD, and industry. It should be noted, however, that a couple of items listed under B9 are being addressed in the Aviation Safety Program's Integrated Vehicle Health Management (IVHM) Project, but because most are being addressed by others, ARMD did not count this topic as one that it is addressing. That said, the IVHM Project has recently released a NASA Research Announcement (NRA) that includes the topic "Prognostics for Power Semiconductor Devices," which is directly relevant to B9.

- Challenge D7 concerns advanced communication, navigation, and surveillance (CNS) technologies. This area is being sufficiently addressed by the extensive research and development activities in other organizations, notably the DOD, the FAA, and industry.

- Challenge D10, safe operation of Unmanned Air Vehicles (UAVs) in the national airspace, was largely covered by the UAVs in the National Airspace System (NAS) project that NASA transitioned to the FAA in FY 2006, in accordance with the direction provided in the Conference Report (House Report 109-272) accompanying H.R. 2862, the FY 2006 Science, State, Justice, Commerce and Related Agencies appropriations bill, which became P.L. 109-108. Specifically, the direction provided was as follows:

  > *"The conferees support NASA's efforts to realign the Aeronautics program by redirecting resources into high-priority activities in support of core competencies in supersonic, subsonic, and hypersonic flight. The conferees urge NASA, as part of this realignment, to ensure a smooth transition of data for certification and policy recommendations from NASA's Unmanned Aerial Vehicles in the National Airspace project to the Federal Aviation Administration (FAA), so that this knowledge is fully available to the FAA for use in the certification process. The conferees direct NASA to provide a report on the findings of the UAVs in the National Air Space project to the FAA no later than February 15, 2006, with a copy of this report to be provided to the Committees on Appropriations."*

  The referenced report was provided to the FAA and to Congress in February 2006.

  That said, much of the research that ARMD conducts has applicability to both manned and unmanned vehicles. More specifically, future unmanned aircraft face a variety of fundamental technical challenges including: development of guidance, navigation and control laws; interactions between the aerodynamics, elasticity and actuators for the airframe (aero-servo-elasticity, flutter); airframe/propulsion system interactions; excess weight and reduced performance; and validation and verification of flight software with hardware in-the-loop. Much of the research in the Fundamental Aeronautics Program will directly address these UAV-relevant challenges in addition to ensuring that their environmental impact (noise and emissions) is limited. Every project within the Aviation Safety Program will produce tools, concepts, methods and technologies that will improve the safety attributes of a wide range of air vehicles, including UAVs. Furthermore, fundamental research on validation and verification of flight software conducted in the Aviation Safety Program is directly applicable to UAVs. Finally, research in the Airspace Systems Program will enable all air vehicles, including UAVs, to operate effectively and efficiently in the NextGen. However, despite the fact that much of ARMD's research has obvious applicability to unmanned platforms, the item has been colored red in the cross-walk matrix because the Survey focused this Challenge on areas not appropriate for NASA. For example, NASA should not be developing training programs for UAV operators, nor should NASA be developing secure and reliable communications for UAVs. Furthermore, it should be noted that the DOD has invested significantly in sense-and-avoid technologies for UAVs and NASA investment in this area would be duplicative.

Beyond the top 51 R&T Challenges:

While ARMD is currently investing in 92 percent of the R&T Challenge Areas recommended by the NRC, it is worth pointing out that the ARMD research portfolio is actually broader in scope than those 47 R&T areas. The reason for this is two-fold. First, the NRC used a weighting scheme that made capacity, safety, and reliability significantly more important than energy and the environment, efficiency, and performance. NASA strongly believes that all of these elements are equally important to enable the NextGen vision. Indeed, during the past year, the JPDO has significantly elevated the importance of environmental compatibility and fuel efficiency in its planning efforts due to the recognition that increasing the capacity of the airspace system without addressing environmental and efficiency concerns will not yield significant gains. In addition, the National Aeronautics R&D Policy considers the principles of mobility (which includes capacity), safety, environmental protection, and energy availability and efficiency to be of equal importance. So, for example, item B11 in the Decadal Survey, "Alternative fuels and additives for propulsion that could broaden fuel sources and/or lessen environmental impact," did not make the "top 51 list", but ARMD considers this an area worthy of investment, and is partnering with the DOD and the FAA to explore the potential of alternative fuels (e.g., Fischer-Tropsch fuels from both fossil and renewable feedstocks).

Second, while the majority of research conducted by ARMD does focus on what the NRC would consider "civil aeronautics applications," ARMD recognizes that it also serves the very unique role of pursuing aeronautics research that is relevant and critical to NASA's human and robotic space exploration activities. It is not possible to travel through the atmosphere of any planet (including that of Earth) without invoking aeronautics principles. Therefore, some of the research conducted in ARMD's Supersonics and Hypersonics Projects focuses on advancing the Agency's knowledge in aeronautical areas critical to entry, descent, and landing (EDL). This is consistent with the direction provided by the National Aeronautics R&D Policy:

"NASA should maintain a broad foundational research effort aimed at preserving the intellectual stewardship and mastery of aeronautics core competencies so that the nation's world-class aeronautics expertise is retained. These core competencies also include key aeronautical capabilities that support NASA's human and robotic space activities."

The Decadal Survey, however, assigned a very low weighting to the strategic objective of support to space, which resulted in low overall scores for any research challenges that support the Agency's space mission. As an example, item A15 in the Survey, "Decelerator technology for planetary entry," scored very high in its mission alignment (because it is aligned to the overall Agency mission), lack of alternative sponsorship (there is no other entity that has responsibility for this research), and appropriate level of risk. Nonetheless, it did not make it into the "top 51 list".

III. RECOMMENDATION #2

NASA should use five Common Themes to make the most efficient use of civil aeronautics R&T resources:

- *Physics-based analysis tools*
- *Multidisciplinary design tools*
- *Advanced configurations*
- *Intelligent and adaptive systems*
- *Complex interactive systems*

NASA agrees that all of these themes are important, and they are evident throughout the ARMD research portfolio. For example, the common themes of physics-based analysis tools and multidisciplinary design tools are present across all of our programs. NASA strongly agrees with the Survey's finding that

"An important benefit of advances in physics-based analysis tools is the new technology and systems frontiers they open. New concepts often emerge from a greater understanding of the underlying physics offered by new analytical capabilities. NASA, industry, and academia can jointly participate in research into physics-based analysis tools because it is fundamental in nature, publishable, and sharable. This research will take time to mature, yet advances can readily be translated into practice as they occur."

NASA also strongly agrees with the comments regarding multidisciplinary design tools: "The next step in the design of more complex systems involves more than just…gluing together discipline-specific analyses and optimization. New multidisciplinary tools are needed to integrate high-fidelity analyses with efficient design methods and to accommodate uncertainty, multiple objectives, and large-scale systems…"

Across all of ARMD's programs, a four-level approach to research has been defined. These four levels are as follows: (1) conduct foundational research to further our fundamental understanding of the underlying physics (which includes mathematics, chemistry, etc) and our ability to model that physics; (2) leverage the foundational research to develop technologies and computational tools focused on discipline-based solutions; (3) integrate those tools and technologies to develop multi-disciplinary solutions; and (4) address the system-level challenges with system-level optimization, assessment, and technology integration. This philosophy is fully aligned with these first two Common Themes. For more details on ARMD's research philosophy, and how it is implemented across all projects and programs, please visit our website (www.aeronautics.nasa.gov), which contains detailed project plans for research being conducted at all four levels in each project, as well as NRA descriptions. The NRA is the solicitation approach used by ARMD to ensure full and open competition from industry, academia, and non-profit organizations. There are many NRA topics that address various aspects of physics-based modeling and multidisciplinary design tools.

Regarding the theme of advanced configurations, NASA agrees that the pursuit of advanced configurations, such as revolutionary aircraft concepts and advanced structural designs, can foster the implementation of innovative solutions to systems-level challenges. In fact, across the ARMD research portfolio, the focus on physics-based, multidisciplinary design, analysis, and optimization tools with quantified levels of uncertainty will enable virtual expeditions through design space in order to identify advanced configurations that have the greatest possibility of meeting multiple and often conflicting system-level requirements. An example of our research focus on advanced configurations is our research partnership with Boeing and the Air Force in the X-48B, a blended wing body configuration that has the potential of significantly improving the fuel burn, noise, and emissions characteristics of subsonic aircraft. Indeed, ARMD strongly believes that advanced configurations (beyond "tube and wing" designs) are a key enabler to meet the stringent environmental and fuel burn requirements anticipated to be required for the full realization of NextGen. In addition to the X-48B blended wing body concept, ARMD is pursuing a number of additional advanced configurations including cruise-efficient short take-off and landing aircraft, supersonic jets, and advanced rotorcraft.

Regarding the intelligent and adaptive systems theme, which "encompasses aircraft-level challenges aimed at sensing the operational environment, actively responding to that environment, and learning from the resulting interactions," NASA agrees that this is an important theme. For example, within the Aviation Safety Program, both the IVHM Project and the Integrated Resilient Aircraft Control (IRAC) Project are closely aligned with this theme. Specifically, the goal of the IVHM Project is to conduct research to advance the state of highly integrated and complex flight-critical health management technologies and systems. These technologies will enable nearly continuous onboard situational awareness of the vehicle health state for use by the flight crew, ground crew, and maintenance depot. Improved safety and reliability will be achieved by onboard systems capable of performing self-diagnostics and self-correcting of anomalies that could otherwise go unattended until a critical failure occurs. A key enabling technology will be the ability for sharing and processing large amounts of information between the various vehicle subsystems to more accurately diagnose the system health state and execute the logic to self-correct any critical anomalies detected.. The IRAC project will pursue methodologies to enable an aircraft to automatically detect, mitigate, and safely recover from an off-nominal condition that could lead to a loss of control. A key component of the research will be to develop technologies that would enable an aircraft control system to automatically adapt or reconfigure itself in the event of a failed or damaged component.

Finally, NASA agrees that the "air transportation system must be understood as a complex interactive system". Furthermore, NASA agrees with each of the systems issues identified under that theme, and with the cautionary statement that "system models typically examine isolated effects or components within the system, and few models attempt to examine a large range of complex, interactive system effects, especially those involving nondeterministic behaviors." All four of ARMD's programs are working closely together to ensure that safety, performance, environmental challenges, and air traffic management challenges are worked together. For example, the Subsonics Fixed Wing Project in the Fundamental Aeronautics Program is working closely with the NGATS: ATM-Airspace and ATM-Airportal Projects in the Airspace Systems Program to understand what environmental modeling capabilities are needed in airspace and airportal systems modeling tools, and to ensure a means of including advanced aircraft configurations in those models, so that the benefits of those advanced configurations can be adequately understood and assessed. As another example, the Integrated Intelligent Flight Deck Project in the Aviation Safety Program is working closely with the NGATS: ATM-Airportal Project to coordinate research in areas such as runway incursion to ensure that solutions are compatible in the flight deck as well as in the airportal environment. As stated in the National Aeronautics R&D Policy:

"As the science and application of aeronautics progressed, an interdependence developed among the aircraft, the air transportation system, and the people who use these systems, resulting in a ***multi-dimensional, highly integrated aeronautics enterprise****….****Treating the entire system as a whole is complex but necessary****, and requires close coordination among multiple government departments and*

agencies as well as industry, academia, and other non-Federal stakeholders to ensure that the needs of all enterprise users are addressed." [Bold added for emphasis]

IV. RECOMMENDATION #3

NASA should support fundamental research to create the foundations for practical certification standards for new technologies.

The Survey Panel highlighted four specific topics in this area that it believed that NASA should address:

- *Systematic documentation and publication of model and design assumptions from the earliest stage of R&T development, to aid in a technology's ultimate certification.*
- *Ongoing iterative validation of models and design tools—and their specifications—during their development, and verification of models and design tools relative to their specifications.*
- *Generation of databases and models from empirical data to provide a basis for validation and certification.*
- *Establishment of community-accepted metrics, criteria, and methods for validation and certification.*

Regarding the first topic, ARMD has engaged, and will continue to engage, both industry and the FAA from the earliest stages of research and technology development. ARMD recognizes the importance of considering how new concepts and technologies will be introduced into the fleet and airspace. The mechanisms that ARMD has put in place to ensure effective knowledge transfer among all members of the aeronautics community will help to reduce barriers to the certification of novel concepts and technologies. These mechanisms include hosting regular working groups and technical interchange meetings that are open to the broad community; participation in the Commercial Aviation Safety Team (CAST), the FAA's Research Engineering and Development Advisory Committee (REDAC), and several FAA working groups; and publication and dissemination of all research data and results (consistent with national security and foreign policy).

Regarding the second and third topics, ARMD has placed a significant emphasis on validation of all of its models and design tools across its portfolio by using data that already exist, or by collecting data where needed. This focus on validation, and the generation of data to conduct such validation, is prevalent not only in NASA's in-house research, but also in the NRA topics as well, where proposers are asked to specify their approach to validation in the case of model and design tool development, from discipline to multi-discipline level. Furthermore, several NRA topics in all three research programs focus specifically on the collection of high-quality data for the purpose of generating databases that will be accessible to the broad community. A more detailed description of our research in Validation and Verification (V&V) of complex systems is provided below.

Regarding the fourth topic, it is the responsibility of the FAA, as the certifying agency, to establish the community-accepted metrics, criteria, and methods for validation and certification of technologies, but NASA's research will certainly inform these metrics, criteria, and methods. Indeed, the Decadal Survey states that, "The FAA and industry…have the lead when it comes to certification issues." and "Certification is the responsibility of the FAA and the aircraft manufacturers, not NASA." In addition, the National Aeronautics R&D Policy clearly states that the "FAA should conduct research as needed to support certification of the safety and environmental performance of aircraft systems." Nonetheless, it is certainly the case that NASA can and should conduct fundamental research that can enable advancements in the "science of certification" of new technologies, especially as systems become more complex and nondeterministic. One area worthy of more detailed discussion is that of V&V, which is an area of focus in the Aviation Safety Program.

V&V in the Aviation Safety Program:
NASA's vision for Validation and Verification (V&V) is a fully integrated approach to analysis, simulation, and experimental testing. In this vision, analytical methods are used for software verification and for identifying regions of marginal performance in the large complex state space in which systems are operating. Analysis results will be integrated with simulation-based methods for more detailed assessment. Simulation studies will automatically generate test matrices for simulations, experimental testing, and flight-testing. ARMD expects that results of fundamental research will advance the state-of-the-art in the areas of analytical methods, simulation methods, and experimental methods by building upon past advances in formal methods, software safety engineering, nonlinear dynamic hybrid system analysis, and high fidelity testing.

Software is a primary consideration in NASA's V&V vision. The growth in pervasiveness and complexity of software has far surpassed current capabilities to provide efficient methods for assuring its safety, especially within the context of certification. NASA will conduct fundamental research in software safety assurance that involves evaluation of different approaches to safety assurance, with particular focus on approaches consistent with dependability cases. Research in this area will include identification and analysis of software contributions to aviation incidents and accidents, and development of methods that provide sufficient evidence of safety for complex, nondeterministic systems. The research should ultimately contribute to methods, guidelines, and tools for software safety assurance that can transition to regulatory guidance to allow for the certification of new adaptive control systems. NASA will continue to support the efforts in RTCA, an industry-Government standards development organization, Special Committee 205, Software Aspects of Aeronautical Systems, by providing fundamental knowledge to advance the current RTCA/DO-178B "Software Considerations in Airborne Systems and Equipment Certification" guidelines. NASA will also provide knowledge to update the guidelines with new areas such as formal methods.

Analytical Methods:
The traditional way of verifying a software system is through human inspection of the software, simulation, and testing. Current approaches provide no guarantee about the quality of the software system because human inspection of software is limited by the abilities of the reviewers, and because simulation and testing explores only a miniscule fraction of the state space of a moderately complex software system. NASA will focus on the development of analytical methods that establish a theoretical and scientific basis for: (1) design verification of high confidence software systems, and the development of tools and methods for building such systems; and (2) evaluating system performance in a large complex state space. Mathematically rigorous techniques and tools for the specification, design, and verification of software systems are needed, and will include advancements in model checking, theorem proving, static analysis, and runtime monitoring.

Simulation Methods:
Although analysis methods provide insight into robustness issues, and are extremely valuable in predicting problematic regions of operation, simulation-based evaluations are often needed to more thoroughly investigate problematic regions in the state space and assess worst-case combinations of effects. Methods and tools that are needed for application to technologies and systems include: (1) simulation-based robustness analysis tools (such as guided Monte Carlo methods) with automatic test case generation; and (2) simulations that integrate models and data bases for flight dynamics, the propulsion system, and the airframe structure.

Experimental Methods:
Experimental methods provide an important complement to analysis and simulation in that they are not limited by modeling assumptions and can highlight problems in the interaction of hardware and software systems.

The Airborne Subscale Transport Aircraft Research (AirSTAR) testbed is an example of a unique experimental test platform for validation of new and emerging technologies that cannot be safely flight validated with full-scale vehicles. The AirSTAR platform will support high-risk, upset-flight maneuvers in response to damage or environmental hazards, and will enable in-flight damage injection for vehicle health management research. All flight data parameters will be archived to support data mining and failure trending research being conducted at NASA, and all data and analysis algorithms will be made publicly available to the broader research community. The AirSTAR platform will also support validation of structural health assessment technologies through the installation of dynamically scaled modular airframe components, such as the empennage, which can be seeded with certain faults, as well as the installation of representative onboard sensors necessary for degradation assessment.

Summary of V&V efforts in the Aviation Safety Program:
The IVHM and IRAC Projects in the Aviation Safety Program will lead the V&V research efforts for ARMD.

Research on analytical and simulation-based methods will be performed in collaboration with academic and industry research partners using NRAs. In addition, NASA will leverage investment by other government agencies, such as the DOD and National Science Foundation (NSF), in analytical methods. Development of compositional verification techniques for complex and modular system models will be performed in conjunction with the National Coordination Office for Networking and Information Technology Research and Development's High Confidence Software Systems Coordinating Group.

V. RECOMMENDATION #4

NASA should ensure that its civil aeronautics R&T plan features the substantive involvement of universities and industry, including a more balanced allocation of funding between in-house and external organizations than currently exists.

A primary goal across all of the programs in ARMD is to establish strong partnerships involving NASA, other Government agencies, academia, and industry in order to enable significant advancement in our Nation's aeronautical expertise. Every element of the ARMD portfolio targets innovative, pre-competitive research that will enhance the technical sophistication of the nation's aeronautics community. This approach is clearly aligned with the overarching goal of the recently signed National Aeronautics R&D Policy, which is to "*advance U.S. technological leadership in aeronautics by fostering a vibrant and dynamic aeronautics R&D community that includes government, industry, and academia.*"

Because these partnerships are so important, ARMD has implemented several processes to enhance collaboration among NASA researchers, academic institutions, and commercial organizations. One of the primary mechanisms for collaborative involvement is the NRA, which ensures full and open competition for the best and most promising research ideas from academia and industry. One of the key objectives of the NRA investment is to stimulate close collaboration among NASA researchers and NRA award recipients to ensure effective knowledge transfer. During ARMD's first evaluation round in 2006, over 700 proposals were received from more than 110 universities and over 120 other organizations (companies and non-profits). More than 600 highly qualified technical and scientific experts from NASA and other organizations provided thorough reviews of these proposals. From those 700 proposals, 138 were selected for award, representing 74 different organizations from 29 different states plus D.C. A complete list of award recipients can be found on our website at www.aeronautics.nasa.gov. The second evaluation round is well underway and the response continues to be excellent. Each project in each program will conduct at least one solicitation per year.

It should be noted that ARMD's NRA investment increases steadily from $52 million in FY08 to $97 million in FY12. Hence, ARMD will have almost doubled the amount of its NRA research funding in five years, increasing the share of research supported by ARMD performed by external organizations. This is in agreement with the NRC recommendation.

An important consideration, however, is that intellectual collaboration does not require transfer of funds. Another form of intellectual partnership that ARMD is using is the establishment of Space Act Agreements (SAAs) between NASA and industry. These SAAs focus on non-reimbursable collaborations in pre-competitive research. In order to stimulate the transfer of ideas between NASA and industry, a Request for Information (RFI) was released in January 2006. ARMD received more than 230 responses from over 100 different organizations, many of which have already resulted in working collaborations. Specifically, 25 SAA partnerships have already been established in the Fundamental Aeronautics Program, with several others currently in the works, approximately 10 SAA partnerships in the Aviation Safety Program are either established or in works, and about six are either established or being worked in the Airspace Systems Program.

Another way that ARMD is reaching out to stakeholders is through meetings with intellectual leaders in industry and academia. ARMD senior staff frequently travel to companies and universities across the country in order to interact with scientists, engineers, and managers who best understand the research challenges of the aeronautics community. During the past eighteen months, ARMD senior staff have traveled to more than 25 companies and universities, with many more visits planned in upcoming months.

Going forward, each program will continue to hold regular industry working group meetings. In addition, industry partners will be invited to technical interchange meetings where results from ARMD-funded research (both in-house and external) will be presented and discussed. A recent example of this was the Airspace Systems Program Technical Interchange Meeting held March 20-22, 2007, at the Ames Research Center. Approximately 160 people participated from industry, academia, Federally Funded Research and Development Centers (FFRDCs), NASA, and other Government agencies.

ARMD also hosts informal meetings with the aeronautics community on a regular basis (roughly every other month) in order to maintain open lines of communication and to generate discussion in areas of broad interest. These meetings provide participants from industry, academia, and non-profit associations with a forum to share their experiences and express their individual points of view on the particular topic of discussion. As an example of the impact of such discussions, a meeting held in December 2006 focused on aeronautical test facilities, and the dialogue resulted in industry participants deciding to work together to establish the U.S. Industry Test Facilities Working Group under the sponsorship of the American Institute of Aeronautics and Astronautics (AIAA) and its Ground Test Technical Committee (GTTC). The first meeting of this working group was on March 29, 2007 -- one day after the second annual DOD/NASA Wind Aeronautics Facility Users' Meeting, which provides a forum for industry and U.S. government users to meet with DOD/NASA facility operators.

VI. RECOMMENDATION #5

NASA should consult with non-NASA researchers to identify the most effective facilities and tools applicable to key aeronautics R&T projects and should facilitate collaborative research to ensure that *each project has access to the most appropriate research capabilities, including test facilities; computational models and facilities; and intellectual capital, available from NASA, the Federal Aviation Administration, the Department of Defense, and other interested research organizations in government, industry, and academia.*

It should be noted that this recommendation is highly consistent with the following implementation guidelines provided in the National Aeronautics R&D Policy:

NASA, DOD, FAA, JPDO, and other executive departments and agencies as appropriate, should develop a national aeronautics R&D plan comprising national research priorities and objectives, roadmaps to achieve the identified objectives, and timelines…This plan should be coordinated through and published by the NSTC within one year of the signature of this policy and updated every two years thereafter...

NASA, DOD, FAA, and other executive departments and agencies as appropriate, should develop an infrastructure plan, aligned with the aeronautics R&D plan, for managing critical Federal RDT&E assets. The infrastructure plan should identify which assets are considered critical from a national perspective and define an approach for constructing, maintaining, modifying, or terminating these assets based on the needs of the broad user community. This infrastructure plan should be coordinated through and published by the NSTC within one year of the signature of this policy and updated every two years thereafter. [It should be noted that the Policy includes both experimental facilities and computational resources in its definition of RDT&E infrastructure].

Executive departments and agencies conducting aeronautics R&D should engage industry, academia, and other non-Federal stakeholders in support of government planning and performance of aeronautics R&D, and should report to the NSTC within one year of the signature of this policy and every two years thereafter on the results of these interactions.

As a member of the National Science and Technology Council (NSTC) Aeronautics Science and Technology Subcommittee, NASA is working alongside representatives from the DOD, Department of Commerce (DOC), DOE, Department of Homeland Security (DHS), Department of State (DOS), Department of Transportation (DOT), FAA, JPDO, NSF, U.S. International Trade Commission (USITC), Council of Economic Advisors (CEA), Domestic Policy Council (DPC), National Security Council (NSC), Office of Management and Budget (OMB), Office of Science and Technology Policy (OSTP), Office of the Vice President (OVP) and Office of the U.S. Trade Representative (USTR) to develop a National Aeronautics R&D Plan and a National Aeronautics RDT&E Infrastructure Plan as called for by the Policy. The subcommittee is leveraging existing advisory groups and outreach mechanisms from each organization. NASA, DOD, and the FAA, for example, participate in numerous interagency organizations that address particular subjects of long-standing interest. Appendix C contains a list of some of these organizations in which NASA is a major participant. In addition to using these existing outreach mechanisms, the subcommittee is engaging experts in the aeronautics community to solicit their views and opinions by establishing several outreach meetings throughout the year.

The subcommittee is also leveraging resources (e.g., plans, data, outreach activities) from those member organizations that have oversight over RDT&E infrastructure. For example, NASA and the DOD have had a long-standing relationship with respect to testing and experiments through formal mechanisms such as the National Aeronautics Testing Alliance (NATA), that covered wind tunnels and air-breathing propulsion facilities, and through informal mechanisms such as cost and usage policies that benefit both NASA and the DOD. NASA and the DOD have recently signed a new agreement entitled the National Partnership for Aeronautical Testing (NPAT) that replaces NATA with a broadened scope that includes all aeronautical test facilities owned or operated by NASA and DOD. NPAT will be used by NASA and DOD to facilitate the establishment of an integrated national strategy for the management of their respective aeronautics test facilities. It is also intended that NPAT will provide a means for NASA and the DOD to engage with the aeronautics community, including the private sector, to discuss their RDT&E infrastructure needs.

Both the R&D plan and the RDT&E infrastructure plan will be completed and delivered to the NSTC by the end of December 2007. The subcommittee will update these plans every other year.

As mentioned in the response to Recommendation #4, a primary goal across all of the programs in ARMD is to establish strong partnerships involving NASA, academia, and industry in order to enable significant advancement in our nation's aeronautical expertise. Because these partnerships are so important, NASA has put many mechanisms in place to engage academia and industry, including working groups and technical interchange meetings at the program and project level, Space Act Agreements for cooperative partnerships with industry, and the NRA process that provides for full and open competition for the best and most promising research ideas from academia and industry. Cooperative partnerships with industry consortia can result in a significant leverage of resources for all partners and can provide opportunities to test the value of component-technology advances in full system-level contexts.

NASA also recognizes the importance of close coordination with its partners in other Government agencies, to enhance collaboration and avoid duplication of effort. In addition to active participation in the interagency organizations listed in Appendix C, NASA has entered into several formal agreements with its Government partners. In May 2006, NASA and the FAA signed a Memorandum of Understanding (MOU) to coordinate their planning efforts in pursuit of complementary goals in aviation and future space transportation. These goals include aviation safety, airspace system efficiency, and environmental compatibility. In August 2006, NASA signed an MOU with the Air Force (AF) to establish partnerships in aeronautical research in areas of mutual interest. As part of the execution of that MOU, the AF and NASA established an Executive Research Committee to oversee joint research efforts. In January 2007, NASA and the DOD signed the NPAT agreement described above. Finally, NASA anticipates signing an MOU with the Army this year that will facilitate the coordination of research efforts between the two organizations in areas pertaining to rotorcraft aeronautics, including rotorcraft dynamics and control, rotorcraft vehicle structures, rotorcraft propulsion, avionics, rotorcraft aeromechanics, and safety and airspace management.

In addition, NASA is committed to working with its Government partners in the JPDO to provide the high-quality, cutting-edge research and technical excellence required to help develop the NextGen. ARMD has interacted closely with the JPDO throughout its restructuring to ensure proper alignment of its research plans with the needs of NextGen. Specifically, ARMD solicited input from the JPDO during its restructuring and ensured that members of the JPDO served as reviewers of its proposed research plans. In addition to conducting research that directly addresses NextGen challenges, NASA has placed a strong emphasis on active participation in the JPDO, providing personnel, analysis tools, and funding to directly support its functions and activities. In fact, NASA has been heavily involved and integrated into the JPDO NextGen planning process, which has ensured that our programs continue to be closely aligned with NextGen needs. NASA personnel hold several key JPDO positions, including the JPDO deputy director, along with the directors of the Systems Engineering and Analysis Division (SEAD), Enterprise Architecture and Engineering Division (EAED), and the Agile Air Traffic System Integrated Product Team (AATS IPT). The Airspace Systems Program NGATS Technical Integration Manager is on the AATS IPT executive council, and the ASP ATM Airspace Project Principal Investigator is on the AATS IPT steering group. The Fundamental Aeronautics Program Deputy Director and the Subsonic Fixed Wing Project Principal Investigator are members of the Environment Integrated Product Team (EIPT) Steering Group. In addition, the three ARMD programs of Airspace Systems, Aviation Safety, and Fundamental Aeronautics have researchers representing them in the general membership of the Agile, Weather, Safety, Airports, and Environment IPTs along with SEAD and EAED. As the JPDO transitions to its new organizational structure this year, NASA will continue to contribute key personnel to the Divisions and the Working Groups (formerly IPTs).

VII. CONCLUSION

NASA's restructured aeronautics portfolio is based upon three core principles: 1) we will dedicate ourselves to the mastery and intellectual stewardship of the core competencies of aeronautics for the Nation in all flight regimes; 2) we will focus our research in areas that are appropriate to NASA's unique capabilities; and, 3) we will directly address the fundamental research needs of the NextGen while working closely with our agency partners in the JPDO.

Due to timing, and rules of engagement established by the NRC to ensure independence, the NRC Decadal Survey was developed completely independently of the restructuring of the ARMD portfolio. Nonetheless, as this report has shown, NASA's new aeronautics research portfolio is well-aligned with all five of the NASA-specific recommendations in the Survey. This result is a strong affirmation that the ARMD restructuring resulted in a portfolio that will produce relevant and meaningful aeronautical research for the benefit of the broad aeronautics community.

APPENDIX A: SUMMARY OF ARMD PROGRAMS AND PROJECTS

FUNDAMENTAL AERONAUTICS PROGRAM

Program Summary:

The Fundamental Aeronautics (FA) Program is dedicated to the mastery and intellectual stewardship of the core competencies of aeronautics for the Nation across all flight regimes. The long-term research that the FA Program conducts is both focused and integrated across disciplines and will be used to provide feasible solutions to the performance and environmental challenges of future air vehicles. The Program also pursues innovative research ideas and modeling techniques that are relevant to low-cost and reliable access to space as well as the entry phase of planetary exploration. Focused technological capabilities that range from foundational knowledge of underlying physical phenomena to the understanding of the interactions that occur at the system level are pursued and developed by the Program. The results of this pre-competitive research are widely disseminated and available to support the Nation's aeronautics community.

The work in the FA Program directly benefits the public through the development of techniques and concepts for both subsonic and supersonic vehicles that are cleaner, quieter, and more energy efficient. Research efforts in revolutionary configurations, lighter and stiffer materials, improved propulsion systems, and advanced concepts for high-lift and drag reduction all target the efficiency and environmental compatibility of future air vehicles. NASA's space exploration missions will benefit from fundamental technology advances that can impact our ability to both access space and survive the planetary entry, descent, and landing (EDL) phase. The FA Program also helps the country develop and maintain excellence in the aeronautics workforce by providing significant research opportunities in all of its projects.

The FA Program has four projects. The Subsonic Fixed Wing Project will address the challenge that future aircraft need to be quieter and cleaner to meet stringent noise and emissions regulations imposed by the expected growth in the air transportation system (two to three times higher capacity by 2025). These aircraft must also meet challenging performance requirements to make them economically viable alternatives to the existing fleet. The Subsonic Rotary Wing Project will address the technical barriers that constrain rotorcraft from reaching widespread use in civil aviation. These barriers include range, speed, payload capacity, fuel efficiency, and environmental acceptance. The Supersonics Project will conduct research to address the efficiency, environmental, and performance barriers to practical supersonic cruise, as well as the critical issue of supersonic deceleration to enable safe, precision planetary EDL of human and large science missions in any atmosphere. Because all access to space and all entry from space through any planetary atmosphere require hypersonic flight, the Hypersonics Project will tackle the key fundamental research issues required to make hypersonic flight and re-entry feasible.

More details about each Project:

The goal of the *Subsonic Fixed Wing* Project is to conduct long-term, cutting-edge research in the core competencies of the subsonic fixed wing regime, thereby producing knowledge, data, capabilities, technologies, and design tools at the foundational, discipline, multidiscipline and system levels that will enable improved prediction methods and technologies for lower noise, lower emissions (including NOx, CO_2, water vapor, volatiles, unburned hydrocarbons, particulate matter, and soot), and higher performance for subsonic aircraft. Higher performance includes energy efficiency and operability technologies that enable advanced airframe and engine systems. The ten-year strategy includes providing novel test methods and validated prediction tools that can be used to improve system trades for advanced concepts capable of meeting longer-term noise, emissions, and performance targets. The following objectives address the overall project goals:

- Improvements in prediction tools and new experimental methods that provide fundamental properties and establish validation data.

- Noise prediction and reduction technologies for airframe and propulsion systems enabling -52 dB cumulative, below Stage III[1].
- Emissions reduction technologies, alternative fuels, and particulate measurement methods enabling 80 percent reduction in landing and take-off NOx below CAEP/2[2] and 25 percent CO_2 reduction as compared to the Boeing 737 with the CFM56 engine.
- Improved vehicle performance through design and development of lightweight, multifunctional and durable structural components, high-lift aerodynamics, and higher bypass ratio engines with efficient power plants.

Because NASA does not design or manufacture aircraft that can operationally show these improvements, we will use a combination of demonstrated component technologies and system-level assessments to show that these goals could be operationally achieved.

The goal of the *Subsonic Rotary Wing* Project is to conduct long-term, cutting-edge research in the core competencies of the subsonic rotary wing regime, thereby producing knowledge, data, capabilities, technologies, and design tools at the foundational, discipline, multidiscipline, and system levels that will enable improved prediction methods and technologies for lower noise, lower emissions, and higher performance for rotary wing aircraft. Higher performance includes improved speed, range, payload capacity, propulsion efficiency, and control systems for safe operations. Advances in physics-based prediction capabilities will ultimately lead to a more robust industry ability to develop rotorcraft vehicles that fly as designed.

The specific objectives of the research are driven by five key technical challenge areas: power transmission and generation; control theory and information processing and modeling; fluid mechanics, dynamics, and aero-structural coupling; acoustics physics; and solid mechanics and advanced materials. These technical challenge areas are relevant to a broad range of industry and Government programs, inherently force the integration of multiple disciplines, and involve technical issues that are beyond the reach of current prediction tools. Each of the technical challenges brings together the analytical methods and experimental validation data that are required to advance the state of the art in a multidiscipline environment. Innovative solutions to these technical challenges, coupled with the increased ability to predict with certainty the solutions, will drive breakthrough technologies for the rotorcraft industry. Research in the Subsonic Rotary Wing Project includes the following goals:

- Develop design capabilities for low-noise rotorcraft that include the accurate calculation of blade vortex interaction noise, high-speed impulsive noise, and blade/wake interaction noise.
- Develop acoustic propagation techniques that account for atmospheric effects, terrain, and shadowing so that rotary wing vehicles can be optimized for minimal noise impact while retaining performance and handling quality standards.
- Develop a variable-speed rotor concept that incorporates the ability to change rotor rotational speed by 50% without performance or handling qualities penalties.

The goal of the *Supersonics* Project is to conduct long-term, cutting-edge research in the core competencies of the supersonic regime, thereby producing knowledge, data, capabilities, technologies, and design tools at the foundational, discipline, multidiscipline and system levels that will address the technical challenges for two

[1] Stage III refers to a limit imposed by the ICAO (International Civil Aviation Organization) on the maximum allowable noise levels for current aircraft.

[2] CAEP/2 refers to the 2nd stage of regulation recommended by the Committee on Aviation Environmental Protection.

supersonic vehicle classes: practical supersonic cruise aircraft and supersonic descent for High-Mass Mars Entry Systems (HMMES).

The Supersonics Project is organized along the following major technical challenges that have been identified for the two vehicle classes: efficiency (supersonic cruise, light weight and durability at high temperature); environmental challenges (airport noise, sonic boom, high altitude emissions); performance challenges (aero-propulso-servo-elastic analysis and design, cruise L/D); entry, descent, and landing challenges (supersonic deceleration); and multidisciplinary design, analysis and optimization challenges.

The Supersonics Project will develop technologies to enable overland supersonic cruise with civilian and military applications and exploration systems of high mass and precision landing in support of NASA's human and robotic space exploration missions. Research in the Supersonics Project includes the following goals:

- Cruise efficiency, comprising improvements in the airframe and propulsion system of approximately 30 percent vs. the final NASA High-Speed Research (HSR) program baseline.
- Approximately 20 EPNdB of jet noise reduction relative to an unsuppressed jet.
- A reduction of loudness on the order of 30 PLdB relative to typical military aircraft sonic booms.
- Elimination or minimized impact from high-altitude emissions.
- A 20 to 40-fold increase in landed mass, with improved position accuracy.

The *Hypersonics* Project is motivated by the fact that all access to space or planetary orbit, and all entry from orbit into Earth's atmosphere or any planet with an atmosphere, requires flight through the hypersonic regime. The goal of the project is to conduct long-term, cutting-edge research in the core competencies of the hypersonic regime, thereby producing knowledge, data, capabilities, and design tools at the foundational, discipline, multidiscipline, and system levels that will address the technical challenges for two high-payoff NASA-unique missions: Highly Reliable Reusable Launch Systems (HRRLS) and High-Mass Mars Entry Systems (HMMES).

Cutting-edge hypersonics research on HRRLS will enable sustained hypersonic flight through the atmosphere with space-access applications. The research focused on HMMES will result in the development of technologies and concepts that can enable the safe and accurate delivery of large payloads to the surface of Mars. This effort will facilitate the EDL phase of planetary missions and is closely aligned with the Agency's space exploration missions.

The Hypersonics Project will focus its research on addressing some of the hardest challenges in hypersonics including:

- The development of materials for airframe and propulsion applications that can withstand severe temperatures for extended periods of time.
- The development of predictive models for compressible flow, turbulence, heating, ablation, combustion, and their interactions.
- The creation of advanced control techniques for vehicles that fly in the hypersonic flow regime.
- The generation of new experimental techniques that can be used to validate our theoretical and computational models.
- Realizable propulsion systems that integrate high-speed turbine engines or rockets and scramjets
- Tying together all of the close interactions among the airframe, inlet, nozzle, and propulsion systems using a physics-based multidisciplinary design analysis and optimization approach.

AVIATON SAFETY PROGRAM

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Program Summary:

The Aviation Safety Program is dedicated to the mastery and intellectual stewardship of the core competencies of aircraft safety in aeronautics for the Nation. Furthermore, the Program builds upon the unique safety-related research capabilities of NASA to improve aircraft safety for current and future aircraft, and to overcome aircraft safety technological barriers that would otherwise constrain the full realization of NextGen. Currently the U.S. Air Transportation System is widely recognized as among the safest in the world, which can be credited to the vigilance of industry and Government working together. However, looking at the projected increases in air traffic and future system capabilities, this vigilance must continue in order for the United States to meet both the public expectations for safety and the full realization of NextGen. To meet these challenges, the Aviation Safety Program will focus on developing cutting-edge technologies to improve the intrinsic safety attributes of current and future aircraft that will operate in the NextGen. Concurrently, these technologies can be leveraged to support space exploration activities, such as enabling self-reliant and intelligent systems necessary for the long-duration travel requirements of future space vehicles.

The Aviation Safety Program will provide aircraft safety related concepts, tools, and technologies that will help ensure the safety of the nation's Air Transportation System as it transitions to meet the future needs of NextGen. These needs include: the anticipated significant increases in air traffic; increased reliance on automation; increased diversity of vehicles; and increased complexity in the system. The long range goals of the research include: reduced occurrence of in-flight failures; onboard systems capable of self-correcting anomalies; improved crew workload allocation and situation awareness; and advanced flight controls to ensure flight safety during adverse flight conditions. The Aviation Safety Program also helps the country develop and maintain excellence in the aeronautics workforce by providing significant research opportunities in all of its projects.

The Aviation Safety Program has four projects. The Integrated Vehicle Health Management Project addresses the challenge of using a prognostic approach to vehicle health management, in particular the integration, processing, and effective use of large amounts of data across highly integrated and complex flight critical systems. The Aircraft Aging and Durability Project addresses the challenge of improving the operational resiliency of future structures and advanced materials against aging-related hazards. The Integrated Intelligent Flight Deck Project addresses the future challenges to ensure the proper integration of the human operator in a highly automated and complex operational environment. The Integrated Resilient Aircraft Control Project addresses the challenge of using automated adaptive control concepts to prevent the loss-of-control of an aircraft in the event of an upset or off-nominal condition.

More details about each Project:

The goal of the *Integrated Vehicle Health Management (IVHM)* Project is to conduct research to advance the state of highly integrated and complex flight-critical health management technologies and systems. These technologies will enable nearly continuous onboard situational awareness of the vehicle health state for use by the flight crew, ground crew, and maintenance depot. Improved safety and reliability will be achieved by onboard systems capable of performing self-diagnostics and self-correcting of anomalies that could otherwise go unattended until a critical failure occurs. A key enabling technology will be the ability for sharing and processing large amounts of information between the various vehicle subsystems to more accurately diagnose the system health state and execute the logic to self-correct any critical anomalies detected.

The goal of the *Aircraft Aging and Durability (AAD)* Project is to develop advanced diagnostic and prognostic capabilities for detection and mitigation of aging-related hazards. The research and technologies to be pursued will decrease the susceptibility of current and next generation aircraft and onboard systems to premature deterioration, thus greatly improving vehicle safety and mission success. Emerging aircraft are introducing advanced material systems, fabrication techniques, and structural configurations for which there is limited service history. There will be an emphasis in the AAD Project on new material systems/fabrication techniques and the potential hazards associated with aging-related degradation. The intent is to take a proactive approach to identifying aging-related hazards before they become critical, and to develop technology and processes to incorporate aging mitigation into the design of future aircraft. Foundational research in aging science will ultimately yield multidisciplinary design, analysis, and optimization capabilities that will enable system-level integrated methods for detection, prediction, and mitigation/management of aging-related hazards for future aircraft.

The goal of the *Integrated Intelligent Flight Deck (IIFD)* Project is to pursue flight deck related concepts and technologies that will ensure crew workload and situational awareness are both safely optimized and adapted to the future operational environment as envisioned by NextGen. A key component of this research is to investigate methods to automatically monitor, measure, and assess the state of the crew awareness to their assigned task. The scope of IIFD includes the following: development of crew/vehicle interface technologies that reduce the risk of pilot error; development of monitoring technologies to enable detection of unsafe behaviors; development of fail-safe methods for changing the operator/automation roles in the presence of detected disability states; and, development of a comprehensive surveillance system design that enables robust detection of external hazards with sufficient time-to-alarm for safe maneuvering to avoid the hazards. The products of the IIFD Project should enable system designers to eliminate the safety risk of unintended consequences when introducing new and advanced systems into an operational environment.

The goal of the *Integrated Resilient Aircraft Control (IRAC)* Project is to conduct research to advance the state of aircraft flight control automation and autonomy in order to prevent loss-of-control in flight. Taking into account the advanced automation and autonomy capabilities as envisioned by NextGen, the research will pursue methodologies to enable an aircraft to automatically detect, mitigate, and safely recover from an off-nominal condition that could lead to a loss of control. A key component of the research will be to develop technologies that would enable an aircraft control system to automatically adapt or reconfigure itself in the event of a failed or damaged component. These adaptive control concepts will likely have applications to future space exploration missions where vehicles will be required to operate and adapt to unknown flight environments.

AIRSPACE SYSTEMS PROGRAM

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Program Summary:

The Airspace Systems (AS) Program enables the development of revolutionary improvements to, and modernization of, the National Airspace System (NAS), as well as the introduction of new systems for vehicles whose operation can take advantage of the improved, modern ATM system. The users of this technology are the FAA, state and local airport authorities and their systems suppliers, existing and new commercial and personal aviation operators, and the aircraft developers and their system suppliers. The primary goal of the AS Program is to enable new aircraft system capabilities and air traffic technology to increase the capacity and mobility of the nation's air transportation system. The objectives are to maximize operational throughput, predictability, efficiency, flexibility, and access into the airspace system while maintaining safety and environmental compatibility.

The AS Program was restructured during FY 2006 to directly address the air traffic management research needs of the NextGen in collaboration with member agencies of the JPDO. The restructured Program is comprised of two projects: NGATS ATM-Airspace and NGATS ATM-Airportal. These two projects were planned to make major contributions to air traffic needs of the future by the development of en route, transitional, terminal capabilities and surface capabilities. Both projects are, much like the airspace system itself, highly integrated, and pay close attention to information management at critical transition interfaces in the national airspace system. A major goal of the AS Program is to explore and develop concepts and integrated solutions to define and assess the allocation of centralized and decentralized automation concepts and technologies necessary for NextGen.

More Details about Each Project:

The *NGATS ATM-Airspace* Project will develop and explore fundamental concepts and integrated solutions that address the optimal allocation of ground and air automation technologies necessary for the NextGen. The project will focus NASA's technical expertise and world-class facilities to address the question of where, when, how, and the extent to which automation can be applied to moving aircraft safely and efficiently through the NAS. Research in this project will address Four-Dimensional Trajectory Operations, including advances in the science and applications of multi-aircraft trajectory optimization that solves the demand/capacity imbalance problem while taking into account weather information and forecast uncertainties and keeping aircraft safely separated. The project's research will develop and test concepts for advanced traffic flow management to provide trajectory planning and execution across the spectrum of time horizons from "strategic planning" to "separation assurance." The project will also conduct research to explore dynamic airspace configuration that addresses the technical challenges of migrating from the current structured, static homogenous airspace to a dynamic, heterogeneous airspace that adapts to user demand and meets changing constraints of weather, traffic congestion, and a highly diverse aircraft fleet. Ultimately, the roles and responsibilities of humans and automation influence every technical area and will be addressed thoroughly. Specific technical goals of the project include:

- Increasing capacity through dynamic allocation of airspace structure and controller resources;
- Effectively allocating demand through departure time management, route modification, adaptive speed control, etc., in the presence of uncertainty;
- Reducing the capacity-limiting impact of human controlled separation assurance by developing methods to improve sequential processing and merging of aircraft in transition and cruise airspace;
- Developing accurate trajectory predictions that are interoperable with aircraft flight management systems and account for prediction uncertainty growth and propagation;
- Quantifying the performance-enhancing effects of emerging airborne technologies; and
- Developing an approach and computer modeling tools that can evaluate the systematic impact of the research for the NextGen.

The *NGATS ATM-Airportal* Project will enable capacity improvements in the terminal and airport domains to achieve key capabilities of NextGen. The Airportal Project is responding to the need to achieve the maximum possible productivity in the combined use of gates, taxiways, runways, terminal airspace, and other airportal resources. Because every airport is a unique environment, and demand is not expected to increase equally at each airport as the system grows, the project will develop and evaluate a suite of capacity-increasing concepts and the system analysis capability to aid tailoring solutions to specific needs. Specific technical goals include:

- Optimizing surface traffic operations to enable capacity enhancements;

- Exploring transformational approaches, enabled by NextGen capabilities, for increasing airportal throughput;
- Maximizing the capacity of individual runways;
- Maximizing the capacity of multiple runways with airspace and taxi interactions (closely-spaced parallel and converging/intersecting runways);
- Minimizing runway incursion threats in all weather conditions;
- Modeling and predicting wake vortex behavior to enable super density operations;
- Balancing arrival and departure traffic management to enable capacity achievements; and
- Balancing safety and environmental requirements.

AERONAUTICS TEST PROGRAM

NASA's Vision and mission are implemented through its four Mission Directorates. All four of these Mission Directorates, in carrying out their mission for NASA, utilize NASA's major aeronautical test facilities, including wind tunnels and flight operations/test infrastructure. The Aeronautics Test Program (ATP) is designed to corporately manage these aeronautical test assets and sustain and improve NASA's core capabilities in these assets to ensure that a minimum core capability is maintained and available to support the needs and requirements of the Agency and the Nation.

The need for reliable facilities to support future NASA aeronautics research, NASA human and robotic space exploration development, DOD military systems development, and the commercial sector development of new civil aircraft presents the ATP with unique challenges. Today's users are looking for excellent service with extremely dependable test results, yet also demand cost effectiveness and efficiency.

In order to meet the goals of corporate management and sustaining core capability, the ATP is formulated around the following objectives:

- Implement an integrated, consistent approach to the management of major wind tunnels/ground test facilities and flight operations/test infrastructure;
- Accomplish efficient and effective use of NASA's major wind tunnels/ground test facilities and flight operations/test infrastructure and other resources to optimize customer service and to meet national test requirements;
- Ensure stable and competitive prices for ATP facilities;
- Maximize the return on investments through facility modernization, technology development, and sound maintenance strategies;
- Provide a stable level of investment, including maintenance, revitalization, and required upgrades;
- Periodically identify and validate a set of facilities that ARMD and/or the Agency's Shared Capability Assets Program (SCAP) will support;
- Develop a facility divestment and investment plan that supports current and/or long-term missions of NASA, the DOD, and the U.S. Industry; and
- Maintain and develop mutually beneficial testing partnerships between NASA, DOD, other Government agencies, and the U.S. commercial sector.

ATP is responsible for the major wind tunnels/ground test facilities at the Ames Research Center, Glenn Research Center, and Langley Research Center and the Western Aeronautical Test Range (WATR), Support Aircraft, Testbed Aircraft, and the Simulation and Loads Laboratories at Dryden Flight Research Center (DFRC). In order to meet its objectives, the ATP will provide for partial to full funding of the fixed costs for those ATP facilities that have significant projected NASA program usage, and/or that are considered to be national assets for which NASA accepts stewardship responsibilities, and/or for which there are present or future requirements by other Government agencies and/or the U.S. aerospace industry. This will achieve user price and utilization stability for both major wind tunnels/ground test facilities, and flight operations/test infrastructure. In addition, for those assets that are considered to be unique, but for which there is no projected current or future usage, the ATP will provide funds to mothball these facilities.

Significant maintenance activities, beyond routine maintenance, will be performed to improve productivity and reduce operational cost. An investment in test technology and facility upgrades (new capability) will be made. In addition, a university NRA effort is planned wherein the use of one or more ATP assets for development of advanced aerospace technologies will be realized.

APPENDIX B: CROSS-WALK MATRIX

Cross Walk-Matrix Between ARMD Portfolio and Decadal Survey Technical Challenges

	A Aerodynamics and Aeroacoustics		B Propulsion and Power		C Materials and Structures		D Dynamics, Navigation, and Control, and Avionics		E Intelligent and Autonomous Systems, Operations and Decision Making, Human Integrated Systems, Networking and Communications
FA	A1. Integrated system performance through novel propulsion-airframe integration	FA	B1a. Quiet propulsion systems	AvSafe	C1. Integrated vehicle health management	ASP/ AvSafe	D1. Advanced guidance systems	FA/ASP/ AvSafe	E1. Methodologies, tools, and simulation and modeling capabilities to design and evaluate complex interactive systems
FA	A2. Aerodynamic performance improvement through transition, boundary layer, and separation control	FA	B1b. Ultraclean gas turbine combustors to reduce gaseous and particulate emissions in all flight segments	FA	C2. Adaptive materials and morphing structures	ASP	D2. Distributed decision making, decision making under uncertainty, and flight path planning and prediction	ASP	E2. New concepts and methods of separating, spacing, and sequencing aircraft
FA	A3. Novel aerodynamic configurations that enable high performance and/or flexible multi-mission aircraft	FA	B3. Intelligent engines and mechanical power systems capable of self-diagnosis and reconfiguration between shop visits	FA	C3. Multidisciplinary analysis, design, and optimization	FA	D3. Aerodynamics and vehicle dynamics via closed-loop flow control	ASP	E3. Appropriate roles of humans and automated systems for separation assurance, including the feasibility and merits of highly automated separation assurance systems
FA	A4a. Aerodynamic designs and flow control schemes to reduce aircraft and rotor noise	FA	B4. Improved propulsion system fuel economy	FA	C4. Next-generation polymers and composites	AvSafe	D4. Intelligent and adaptive flight control techniques	ASP	E4. Affordable new sensors, system technologies, and procedures to improve the prediction and measurement of wake turbulence
FA	A4b. Accuracy of prediction of aerodynamic performance of complex 3D configurations, including improved boundary layer transition and turbulence models and associated design tools	FA	B5. Propulsion systems for short takeoff and vertical lift	FA	C5. Noise prediction and suppression	AvSafe	D5. Fault tolerant and integrated vehicle health management systems	ASP/ AvSafe	E5. Interfaces that ensure effective information sharing and coordination among ground-based and airborne human and machine agents
AvSafe	A6. Aerodynamics robust to atmospheric disturbances and adverse weather conditions, including icing	FA	B6a. Variable-cycle engines to expand the operating envelope	FA	C6a. Innovative high-temperature metals and environmental coatings	ASP/ AvSafe	D6. Improved onboard weather systems and tools	ASP	E6. Vulnerability analysis as an integral element in the architecture design and simulations of the air transportation system
	A7a. Aerodynamic configurations to leverage advantages of formation flying	FA	B6b. Integrated power and thermal management systems	FA	C6b. Innovative load suppression, and vibration and aeromechanical stability control		D7. Advanced communication, navigation, and surveillance technology	ASP	E7. Adaptive ATM techniques to minimize the impact of weather by taking better advantage of improved probabilistic forecasts
ASP	A7b. Accuracy of wake vortex prediction, and vortex detection and mitigation techniques	FA	B8. Propulsion systems for supersonic flight	FA	C8. Structural innovations for high-speed rotorcraft	AvSafe	D8. Human-machine integration	ASP	E8a. Transparent and collaborative decision support systems
FA	A9. Aerodynamic performance for V/STOL and ESTOL, including adequate control power		B9. High-reliability, high-performance, and high-power-density aircraft electric power systems	FA	C9. High-temperature ceramics and coatings	AvSafe	D9. Synthetic and enhanced vision systems	ASP/ AvSafe	E8b. Using operational and maintenance data to assess leading indicators of safety
FA	A10. Techniques for reducing/mitigating sonic boom through novel aircraft shaping	FA	B10. Combined-cycle hypersonic propulsion systems with mode transition	FA	C10. Multifunctional materials		D10. Safe operation of unmanned air vehicles in the national airspace	ASP/ AvSafe	E8c. Interfaces and procedures that support human operators in effective task and attention management
FA	A11. Robust and efficient multidisciplinary design tool								

FA
AvSafe
ASP
Not Planned Within ARMD
Multiple Program Support

Appendix C: Aeronautics Interagency Organizations

Appendix C: Aeronautics Interagency Organizations

Joint Planning and Development Office (JPDO) - The JPDO is developing the national Plan for the Next Generation Air Transportation System (NGATS). During FY 2007, the JPDO is developing an Enterprise Architecture and an Integrated Work Plan that will provide the information needed for FY 2009 program planning by each member agency. For more information, see www.jpdo.gov. [Principal Members: FAA, NASA, DOT, DOD, DOC, DHS, OSTP]

Commercial Aviation Safety Team (CAST) - Joint objectives to improve aviation safety of commercial aircraft by reducing the fatal accident rate. [Principal Members: NASA, FAA, Industry]

International Helicopter Safety Team (IHST) - Similar to CAST, but focus is on rotorcraft. [Principal Members: NASA, FAA, Industry]

Joint Council on Aging Aircraft (JCAA) - The Joint Aeronautical Commanders' Group (JACG) has focused its resources on the aging aircraft problem. It chartered the Joint Council on Aging Aircraft (JCAA) as the lead board for working a national aging aircraft strategy including identifying and initiating joint R&D efforts. [Principal Members: NASA, USAF, USN, FAA, Defense Logistics Agency (DLA), Army]

Versatile Affordable Advanced Turbine Engine (VAATE) Technology Program -Coordinates turbine engine science and technology (S&T) across DOD and other government agencies (NASA, DOE). Reviews national turbine engine technology roadmaps and progress towards achieving roadmap goals. Interfaces with industry to link government and industry activities in turbine engine S&T. Communicates benefit and need for turbine engine technology S&T to government agencies and industry. [Principal Members: NASA, ODUSD(S&T), USAF, USN, USA, DOE, Industry]

Vertical Take-off and Landing (VTOL) Science and Technology (S&T) Partnership Council - Provides a forum for planning, allocating resources, and executing the Joint Services VTOL S&T Program. Facilitates strategic direction to the Fixed- and Rotary-Wing S&T community. The Council will establish strategic direction and provide the necessary oversight of the S&T process. [Principal Members: NASA, ODUSD(S&T), USAF, USN, USA]

Hypersonics Joint Technology Office (formerly the High-Speed / Hypersonics Steering Committee) - Provides a forum for planning, allocating resources, and executing the Joint Services High-Speed and Hypersonic S&T Program. [Principal Members: ODUSD(S&T), USAF, USN, USA, NASA]

Aircraft Icing Research Alliance (AIRA) - Objective of AIRA is to coordinate collaborative aircraft icing research activities that improve the safety of aircraft operations in icing conditions. Current partners are: NASA, FAA, NOAA, Environment Canada, Transport Canada, Canadian National Research Council, and the UK Defense Science and Technology Laboratory. Every three years this alliance prioritizes research topics and creates collaborative tasks. Current tasks include the development of icing cloud instrumentation by NASA, the FAA, the NRC, and the Meteorological Services of Canada (MSC); high ice water content research by NASA, the FAA, and the MSC; and icing environment remote systems development by NASA, NOAA, the FAA, Transport Canada, and the MSC. [Principal Members: NASA, FAA, NOAA]

Fixed-Wing Executive Council - Coordinates national strategy in this technical area among major Government and industry partners. Participants from USAF, NASA, Army, Navy, and OSD meet with Northrop Grumman, Lockheed Martin, and Boeing three times a year to share opportunities to collaborate, discuss future national direction, and develop strategies to meet warfighter needs. Promote the program at appropriate levels of government and industry. Provide strong leadership to continuously inspire the team, instill discipline, articulate the team's position at executive levels, and ensure a strong focus on the goals. [Principal Members: NASA, ODUSD(S&T), USAF, USN, USA, Industry]

National Partnership for Aeronautical Testing (NPAT) Council - Council will implement the NPAT agreement between NASA and the DOD. The purpose of the NPAT agreement is to expand cooperation between the two parties and to facilitate the parties' establishment of an integrated national strategy for the management of their respective aeronautical test facilities. [Principal Members: NASA and DOD]

NASA/AF Executive Research Committee - Responsible for the executive direction and oversight of AF and NASA joint aeronautics research and development efforts. Responsibilities include: (1) Fostering an effective AF/NASA partnership in research, development, and applications; (2) Ensuring that AF and NASA planning and resources to achieve the objectives are coordinated, when appropriate; (3) Monitoring progress toward the goals and proposing adjustments in the organizations' roadmaps, plans, and resources, as necessary; and (4) Proposing changes to goals and plans based on changing stakeholder and customer requirements. [Members: NASA and USAF]